

ARES V OVERVIEW AND STATUS

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ABSTRACT

As part of NASA's Constellation Program to resume exploration beyond low Earth orbit (LEO), the Ares V heavy-lift cargo launch vehicle as currently conceived will be able to send more crew and cargo to more places on the Moon than the Apollo Program Saturn V. (Figure 1) It also has unprecedented cargo mass and volume capabilities that will be a national asset for science, commerce, and national defense applications. Compared to current systems, it will offer approximately five times the mass and volume to most orbits and locations.



Fig. 1: The Ares V first stage boosters are jettisoned as the vehicle heads for orbit in this artist's depiction of the Ares V mission.

The Columbia space shuttle accident, the resulting investigation, the Vision for Space Exploration, and the Exploration Systems Architecture Study (ESAS) broadly shaped the Constellation architecture. Out of those events and initiatives emerged an architecture intended to replace the space shuttle, complete the International Space Station (ISS), resume a much more ambitious plan to explore the moon as a stepping stone to other destinations in the solar system.

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The Ares I was NASA's main priority because of the goal to retire the Shuttle. Ares V remains in a concept development phase, evolving through hundreds of configurations. The current reference design was approved during the Lunar Capabilities Concept Review/Ares V Mission Concept Review (LCCR/MCR) in June 2008. This reference concept serves as a starting point for a renewed set of design trades and detailed analysis into its interaction with the other components of the Constellation architecture and existing launch infrastructure.

In 2009, the Ares V team was heavily involved in supporting the Review of U.S. Human Space Flight Plans Committee. Several alternative designs for Ares V have been supplied to the committee.

This paper will discuss the origins of the Ares V design, the evolution to the current reference configuration, and the options provided to the review committee.

Introduction

The Ares V will be the largest launch vehicle in history. It is designed as the cargo vehicle for supporting human exploration beyond LEO. It also has unprecedented capability to a variety of payloads supporting astronomy, planetary science, national defense, or commercial missions. Ares V is a part of the Constellation Program, which includes the Ares I crew launch vehicle, the Orion crew spacecraft, the lunar lander, and lunar surface systems.

The Constellation architecture was shaped by the Columbia space shuttle accident, the resulting investigation, the Vision for Space Exploration (VSE), and the Exploration Systems Architecture Study (ESAS).¹ Out of those events and initiatives emerged an architecture intended to replace the Space Shuttle with a much safer system, complete the International Space Station (ISS), resume a much more ambitious plan to explore the moon as a stepping stone to other destinations in the solar system.

The architecture separates crew from cargo transportation to minimize the risks to human life. It relies where possible on proven technologies from the Shuttle, Apollo, the current commercial launch vehicle fleet. It also seeks to minimize risk and cost by employing commonality between vehicles.

The Ares V is designed to launch the Earth departure stage (EDS), carrying the lander, into low Earth orbit (LEO). The Ares I is designed to put Orion and crews of up to four initially for missions to the ISS or to rendezvous with the Ares V for lunar missions. The crewed lunar mission profile is shown in Figure 2.

The Constellation architecture is designed to be safer, more reliable, and more efficient than the Space Shuttle fleet and its associated infrastructure. The Ares I first stage is a five-segment solid rocket motor based on the current 4-segment Shuttle booster. The upper stage is powered by a single J-2X engine based on the Apollo-era J-2. The Ares V is the same 33-foot diameter as the Saturn V first stage. The six RS-68B engines on the Ares V core stage are upgraded variants of the RS-68 now used on the Delta IV vehicle. The first stage boosters use a 5 1/2-segment solid rocket motor based on the Ares I first stage. The EDS uses a single J-2X engine from the Ares I upper stage, with modifications based on the orbital restart and trans lunar injection (TLI) requirements. That proven technological heritage is illustrated in Figure 3.

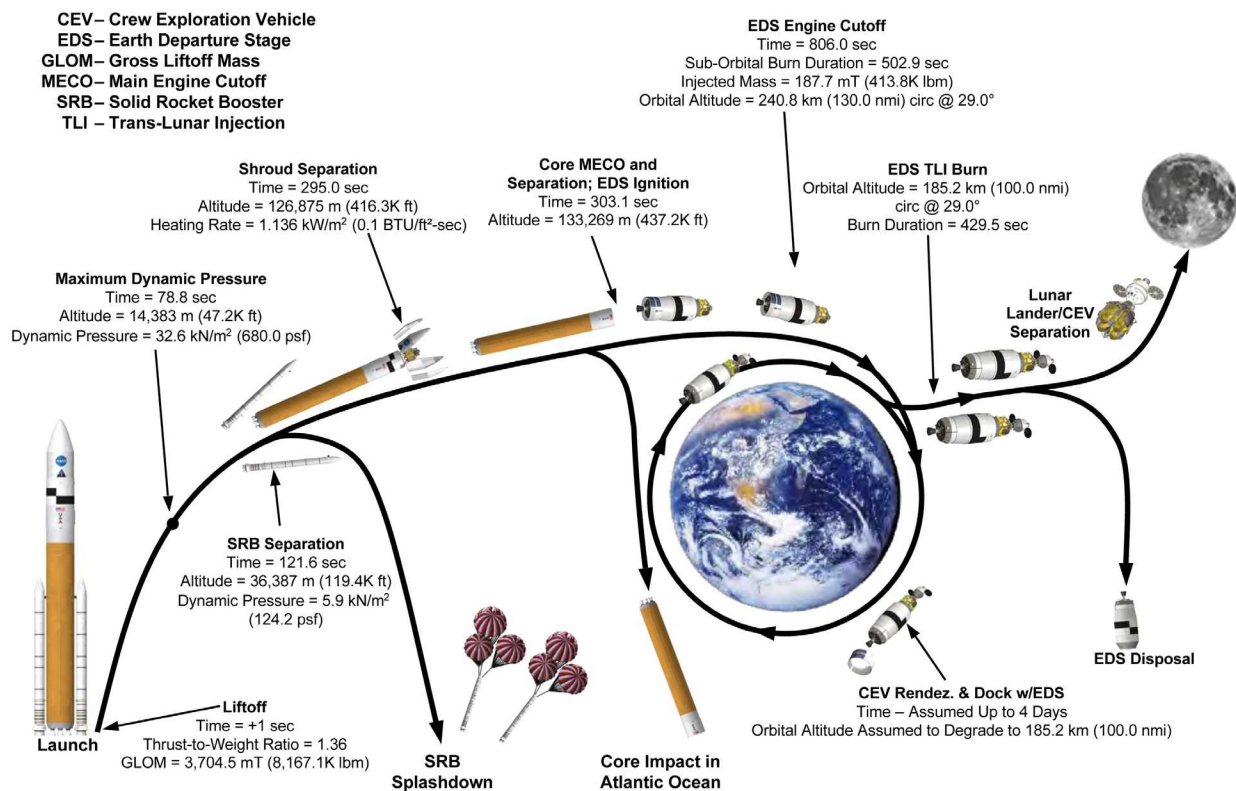


Figure 2. Ares V Launch Profile for the Lunar Sortie Mission.

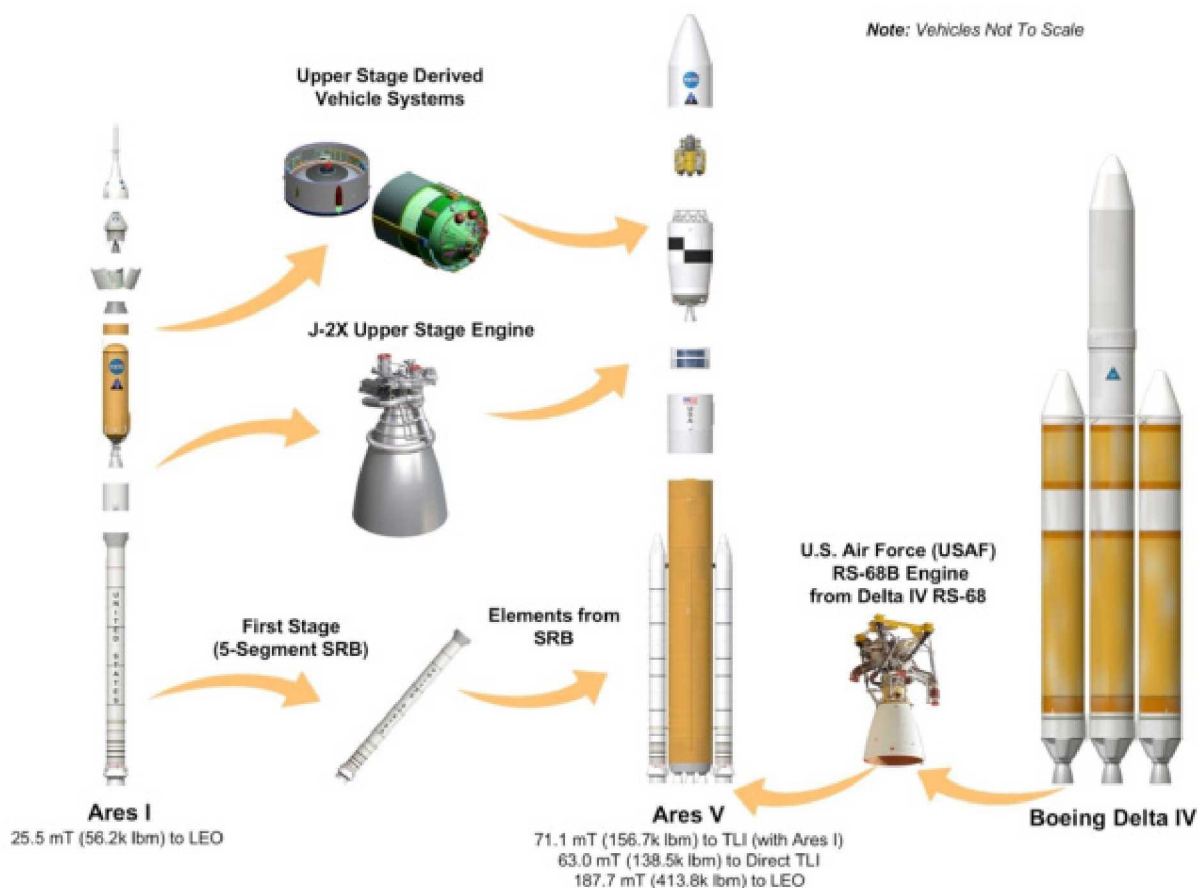


Fig. 3: Ares V main propulsion hardware heritage is illustrated above.

Design Background

While retaining the goals of heritage hardware and commonality, the Ares V configuration continues to be refined through a series of internal trades. The Ares V team evaluated more than 1,700 vehicle configurations leading to the current reference configuration selected at LCCR.² That total has risen to more than 2,000 configurations since. A key driver for these trades is the Constellation Architecture Requirements Document (CARD), which can be traced back to ESAS. The CARD provides the mass requirements for both the Lunar Sortie (crewed) and Lunar Cargo (automated) design reference missions (DRMs). The CARD requirements are shown in Figure 4.

The CARD requirements, combined with goals for safety, reliability, and cost were used to trade hundreds of combinations: two- vs. three-stages, five vs. six core stage engines, five vs. five-and-a-half segment boosters, 27.5- vs. 30-foot core and upper stages, extended core and earth departure stages, materials for “wet” and “dry” structural applications, and other technologies intended to improve performance. A summary of key milestones in the trade studies leading to the current point of departure (POD) is shown in Figure 5.

The most recent POD configuration, designated 51.00.48, was recommended by the Ares Projects and approved by the Constellation Program during the LCCR in June 2008. This configuration is the basis for the ongoing Ares

Lunar Sortie Mission			
CARD Requirement	Mass (t)	Mass (lb _m)	Derived Performance Rqt.
Orion [CA4139]	20.2	44,500	
Crewed Lander [CA0836]	45.0	99,208	
Total TLI [CA0848]	66.9	147,575	Derived TLI > 66.9 t
	45.0	99,208	Derived ETO > 45.0 t

Lunar Cargo Mission			
CARD Requirement	Mass (t)	Mass (lb _m)	Derived Performance Rqt.
Cargo Lander [CA5231]	53.6	118,168	
Total TLI [CA0847]	54.6	120,372	Derived TLI > 54.6 t
Total ETO Goal [CA0847]	54.6	120,372	Derived ETO > 54.6 t

Figure 4. Ares V performance requirements for lunar crew and lunar cargo missions.

For the sortie mission, the CARD specifies an Orion control mass of 44,500 lb (20.2 mT) and a lunar lander control mass of 99,208 lb (45 mT). The total TLI payload requirement is 147,575 lb (66.9 mT). The Lunar Sortie mission assumes a LEO destination orbit of 130 nautical miles (nmi) at 29 degrees inclination. The TLI maneuver begins at a minimum 100 nmi altitude with a ΔV requirement of 10,417 ft (3,175 m) per second (m/s) plus gravity loss.

For the cargo mission, the CARD specifies a lander control mass of 118,168 lb (53.6 mT) and a total TLI payload mass of 120,372 lb (54.6 mT). The Lunar Cargo mission assumes a phasing orbit Earth-To-Orbit (ETO) destination.

V Integration Study which seeks to define and resolve design issues between the Constellation requirements and interrelationships between major Ares V components.

The latest POD defines the Ares V as 381 feet (116m) tall with a gross lift-off mass (GLOM) of 8.1 million pounds (3,704.5 mT). Its first stage will generate 11 million pounds of sea-level liftoff thrust. It will be capable of launching 413,800 pounds (187.7 mT) to low Earth orbit (LEO), 138,500 pounds (63 mT) direct to the Moon, or 156,700 pounds (71.1 mT) in its dual-launch architecture role with Ares I.

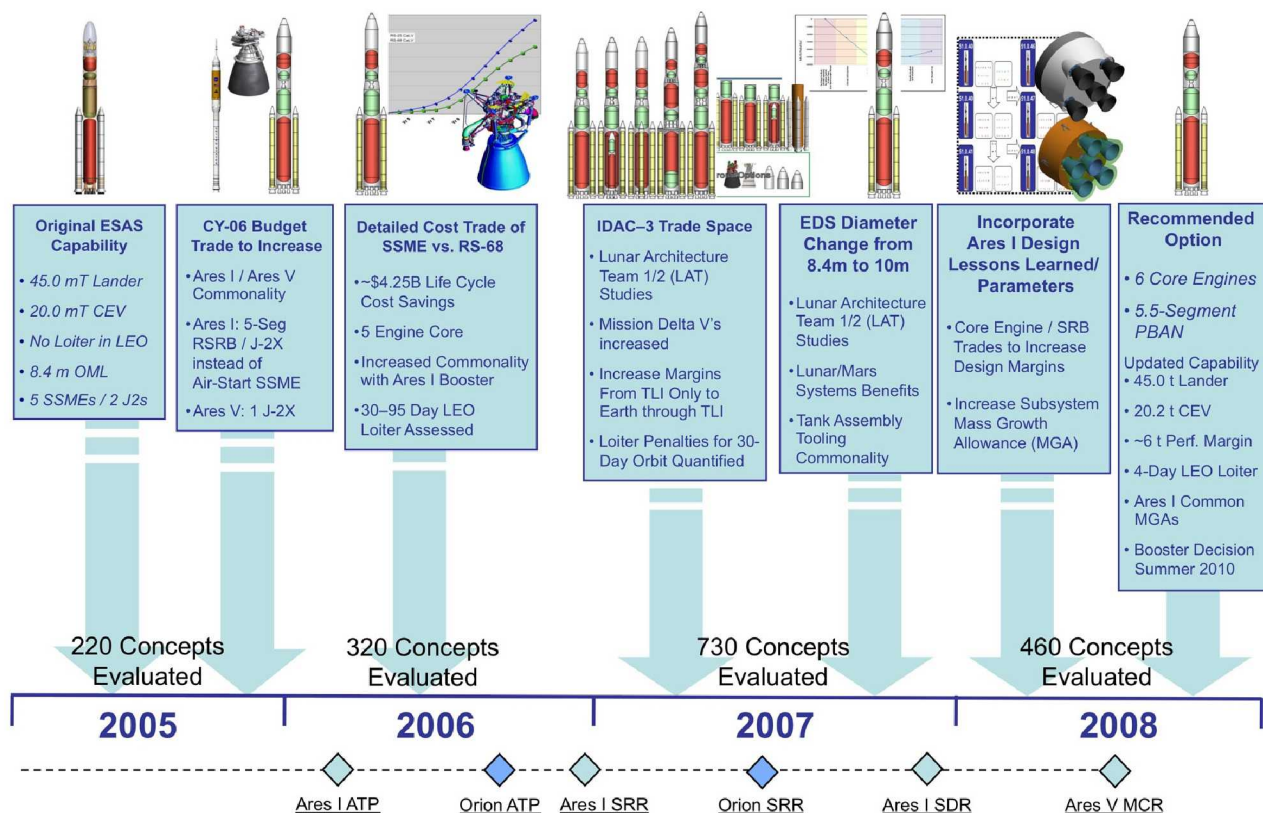


Figure 5. ESAS to Summer 2008 Ares V key configuration studies and refinements.

By comparison, the Apollo-era Saturn V was 364 feet (111 m) tall, with a gross liftoff mass of 6.5 million pounds (2,948.4 mT), and could carry 99,000 pounds (44.9 mT) to TLI or 262,000 pounds (118.8 mT) to LEO. In conjunction with Ares I, Ares V can launch 58 percent more payload to TLI than the Saturn V.

As shown in the expanded vehicle overview (Figure 6), the Ares V first stage propulsion system consists of a core stage powered by six commercial liquid hydrogen/liquid oxygen (LH₂/LOX) RS-68 engines, flanked by two 5.5-segment solid rocket boosters (SRBs) based on the 5-segment Ares I first stage. The boosters use the same Polybutadiene Acrylonitrile (PBAN) propellant as the Ares I and Space Shuttle. Atop the core stage is the Earth departure stage (EDS), powered by a single J-2X upper stage engine based on the Ares I upper stage engine.

This configuration and its performance is expected to be capable of carrying out the lunar sortie mission based on the required CARD masses for Orion and the lunar lander. However, it falls short of the Ares Projects internal TLI payload goal of 165,567 pounds (75.1 mT) that attempts

to accommodate the magnitude of mass increases and performance losses for the Ares vehicles, Orion and the lander typical in new vehicle development. The Ares Projects are carrying an option for a new composite case booster with more energetic Hydroxyl-terminated Polybutadiene (HTPB) propellant that would meet the desired TLI goal. That concept is designated 51.00.39. In the current mission profile (Figure 4), the Ares V launches from Kennedy Space Center, Florida. The boosters separate, followed by the core stage. The EDS ignites at altitude and places the stage and its payload into a stable parking orbit. Shroud separation occurs following EDS ignition to avoid shroud re-contact with the vehicle. The Orion, launched by the Ares I, rendezvous and docks with the lander. Following automated and ground checkouts, the EDS re-ignites and performs the TLI burn to send the combined vehicles toward the Moon. The EDS is discarded en route, completing the Ares portion of the lunar mission. The current concept of operations calls for an Ares V launch as early as 90 minutes after Ares I, with 3 subsequent launch opportunities over the next 3 days. Ares V is currently designed to sustain a 4-day loiter, with TLI on the fourth day.

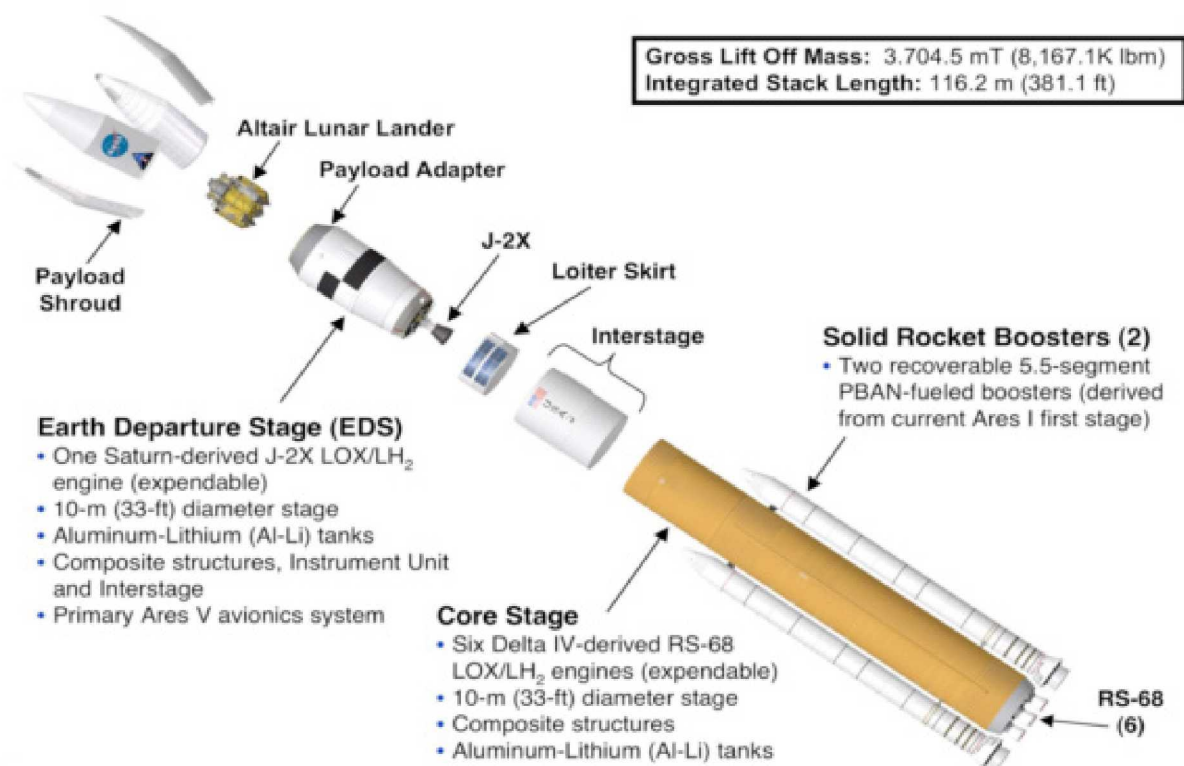


Fig. 6: Expanded view showing key components of the current Ares V reference launch vehicle.

Technical Status

Ares V remains in a pre-design analysis cycle stage pending a planned late calendar 2010 authority to proceed (ATP) to the formal design phase. The Ares Projects continue to refine the Ares V design through a variety of internal studies. In addition, Ares V benefits from the decision to use heritage hardware as a point of departure and from the goal to seek commonality with Ares I. The following sections will discuss the major components of the Ares V launch vehicle and their technical status.

Ares V Core Stage

The design team continues to evaluate options for the core stage design. The LCCR added a sixth engine to the core. Engineering analysis has examined numerous impacts, such as engine arrangement, stage thrust structure, materials, and base heating of the new configuration. The team has also maintained its relationship with the U.S. Air Force, which is developing a variant of the Pratt & Whitney RS-68 with improved performance. That RS-68A version will serve as the basis for NASA's RS-68B. A summary of the changes is shown in Figure 7.

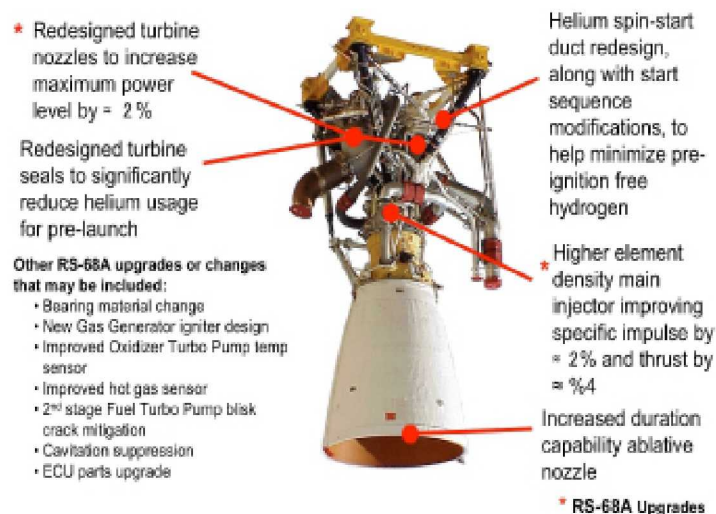


Fig. 7: Summary of changes planned for Pratt & Whitney RS-68 engine.

The A variant increases specific impulse and thrust. The B variant would increase operational life of the nozzle and decrease helium usage and pre-ignition of free hydrogen on the launch pad. Based on initial engine testing by the Air Force, NASA is evaluating further upgrades to the engine to meet Constellation performance goals. Other analysis has covered stage weight estimates and loading, thermal protection, controllability, and engine gimbaling requirements. Because the core stage is discarded so early in the mission, the performance penalty of solving design problems with mass is less than for any other part of the vehicle. The use of lighter materials and more complex design solutions, therefore, is better devoted to the EDS, which is carried to TLI and benefits from lighter weight and higher performance. The basis for this study is the LCCR POD, which increased the key dimensions of the stage. The hydrogen tank was increased 13.3 feet in length beneath the SRB crossbeam support. To maintain the required engine mixture ratio and accommodate the longer SRB, the LOX tank was stretched 4.9 feet above the SRB crossbeam attachment. The stage now measures 233.9 ft (71.3 m) in length and 33 feet (10 m) in diameter.

First Stage Solid Rocket Booster

The Ares V first stage booster is derived from the current Space Shuttle 4-segment steel case solid rocket booster (SRB). It is also designed for commonality with the Ares I first stage booster, employing the same design, manufacturing facilities, tooling, and experienced workforce. The current design is illustrated in Figure 8.

The booster consists of five normal-sized booster segments and one half segment, which contains 119,450 pounds (54,181 kg) of added propellant and field joints on both ends. The booster uses the same heritage PBAN propellant used by the Shuttle boosters and the Ares I first stage. The Ares V booster is approximately 160 inches (4m) longer than the Ares I 5-segment booster design. The design increases total propellant weight and permits a longer Core Stage with additional Core Stage propellant. The design uses heritage steel case cylinders and domes, as well as aft skirt, forward skirt, frustum, and nose cone. The core stage-to-booster attach cylinder of the aft segment and the

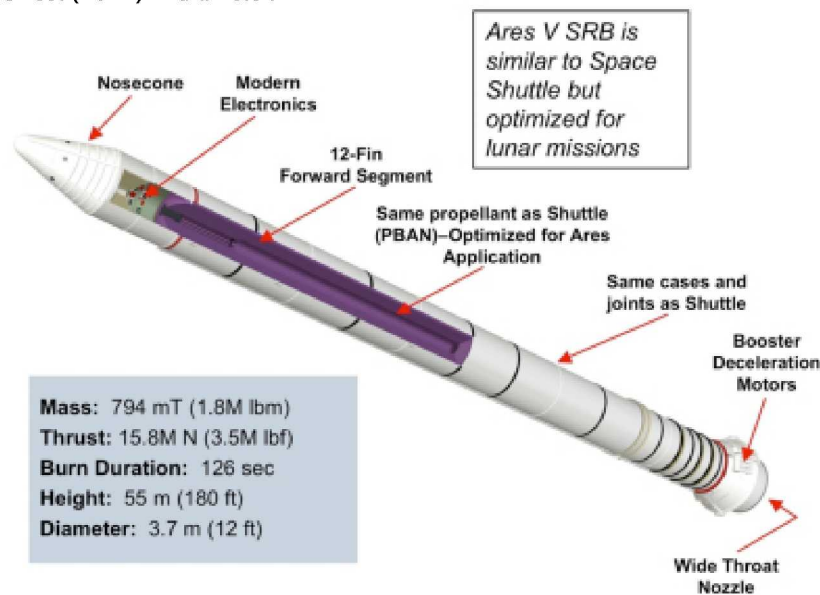


Fig. 8: 5-segment SRB for Ares V.



Fig. 9: Full lateral view of the Ares I first stage five-segment development motor in its test stand at ATK in Promontory, Utah. (Credit: ATK)

attach ring/struts are assumed to be Shuttle RSRB heritage. The case design maximum expected operating pressure is the same as the Shuttle RSRM and Ares I booster design. To achieve the same operating pressure, the nozzle throat diameter was widened five inches (0.127 m) larger than the current Shuttle booster. The widened throat enables more propellant to be expelled at the same pressures as the Shuttle Redesigned Solid Rocket Motor (RSRM). The Ares V boosters are designed to be recovered.

Development progress with the Ares I first stage also benefits the Ares V booster. The Ares I booster has made significant progress. Having already developed an exhaust nozzle process simulation article (PSA) and recovery parachutes and fired a range of test motors, two new major milestones were scheduled for 2009. Development Motor 1 (DM-1), shown in Figure 9, was scheduled for test firing in September 2009. It is the first full size firing of a five-segment SRB.

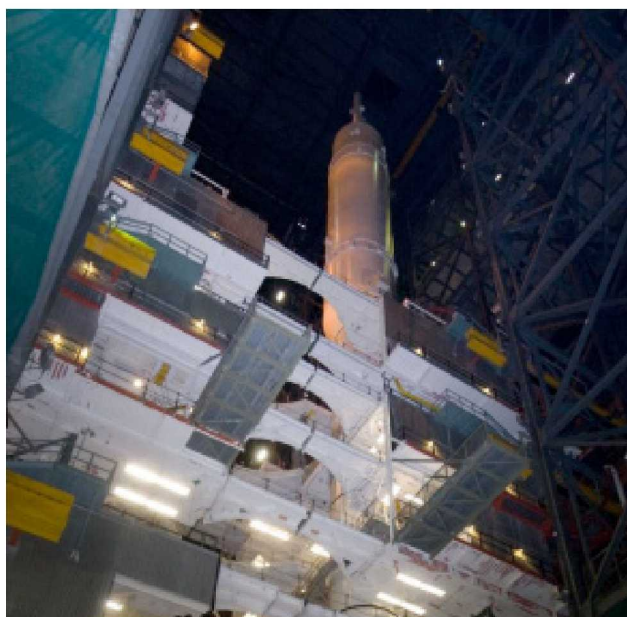


Fig. 10: Stacked Ares I-X stands 3237 feet tall in the VAB at KSC.

The launch of Ares I-X was scheduled for no earlier than Oct. 31, 2009. Stacking was complete in August 2009, as shown in Figure 10. The test vehicle uses a four-segment shuttle motor to test control system logic, aerodynamic forces, motor internal forces, ground assembly, vehicle integration, recovery performance, and vehicle integration. Other Ares I first stage accomplishments include the Ares I-X forward skirt extension separation test, main parachute drop test, DM-1 igniter test and the DM-1 test itself.

Earth Departure Stage and Payload Shroud

The Earth Departure Stage (EDS) will be the stage most directly responsible for sending both human and cargo from LEO to lunar orbit. An expanded view of the reference configuration is shown in Figure 11.

The baseline EDS for the pre-LCCR studies comprised a 33-foot-diameter stage with metallic structures capable of delivering a 106,000-pound Altair to LEO and supporting a 4-day loiter period. Several options for weight reduction are under consideration: greater use of composites, use of nested, conformal, and common bulkhead tanks, dual use of structures as micrometeoroid and orbital debris (MMOD) protection; reducing consumables; transferring weight from the EDS to the core stage, and jettisoning loiter hardware prior to the TLI burn. Loiter equipment could be grouped into kits, depending on the mission needs and loiter duration. A typical kit might include MMOD protection, propellant reconditioning equipment and insulation, and an MMOD skirt for the J-2X engine.

Again, due to efforts to seek commonalities between Ares I and Ares V, progress in the Ares I upper stage element will have application to the EDS. Two examples are pictured in Figure 12.

Milestones in upper stage development include the first friction stir weld of Shuttle External Tank dome gore panels to test the welding process and the robotic welding tool itself. Also complete was the first full upper stage manufacturing demonstration article (MDA) dome, composed of a number of upper stage panels. Other accomplishments include the ullage settling motor system heavy weight motor hot-fire testing, Ares I roll control engine thruster testing, delivery of the Upper Stage reaction control system development test article, completion of the thrust vector control 2-axis test rig, common bulkhead seal weld process development, and aluminum lithium panel structural buckling testing. Additionally, the Ares I Vertical Milling Machine has been installed and will be operational by October of this year, and the Upper Stage Thermal Protection System (TPS) Spray Booth Installation Facility will be fully operational by December 2009. Although the upper stage is 18 feet in diameter, while the EDS will be 33 feet in diameter, the materials, assembly and general effort at weight reduction will be applicable to EDS development.

The biggest challenge for the EDS continues to be cryogenic fluid management. NASA's previous loiter experience was three hours for the Saturn S-IVB third stage. Other issues to be addressed are supporting J-2X conditioning and restart. Heat from the initial J-2X firing will tend to go into the stage and must be attenuated.

Shroud design work is focused on the tangent ogive shape instead of the biconic shape traded previously. Analysis has shown that the tangent ogive has lower drag and lower acoustic loads caused by vortex shedding. If the shroud is made of composite materials, tangent ogive probably will be easier to manufacture. It would also have better usable internal volume. A decision to use a metal shroud might push the design back to biconic, however. The Shuttle External Tank liquid oxygen tank uses a tangent ogive design, but it is time consuming to produce.

J-2X Upper Stage Engine

The J-2X upper stage engine will put the EDS in orbit and then re-start up to four days later to complete the TLI burn and send the Orion and lunar lander to the Moon. The J-2X is designed to retain its Apollo-era predecessor's simpler gas generator cycle, yet provide both higher thrust and

higher efficiency than the proven J-2. This will help J-2X meet the greater Constellation performance demands and meet the goal of commonality by powering both the Ares I Upper Stage and the Ares V EDS. The gas generator, main controller, main injector and main combustion chamber are derived from the current RS-68 engine design. Turbomachinery and ducts are based on the J-2S development in the 1970s.

The J-2X is required to operate in primary or secondary modes. In primary mode for the Ares I and Ares V ascents to orbit, it will provide 294,000 pounds of thrust. In secondary mode for the Ares V TLI burn, it is designed to operate at 242,000 pounds of thrust by changing the propellant mixture ratio from 5.5 to 4.5. This requirement is the result of an effort to lower the loads on the docking system between the mated Orion and lunar lander vehicles.

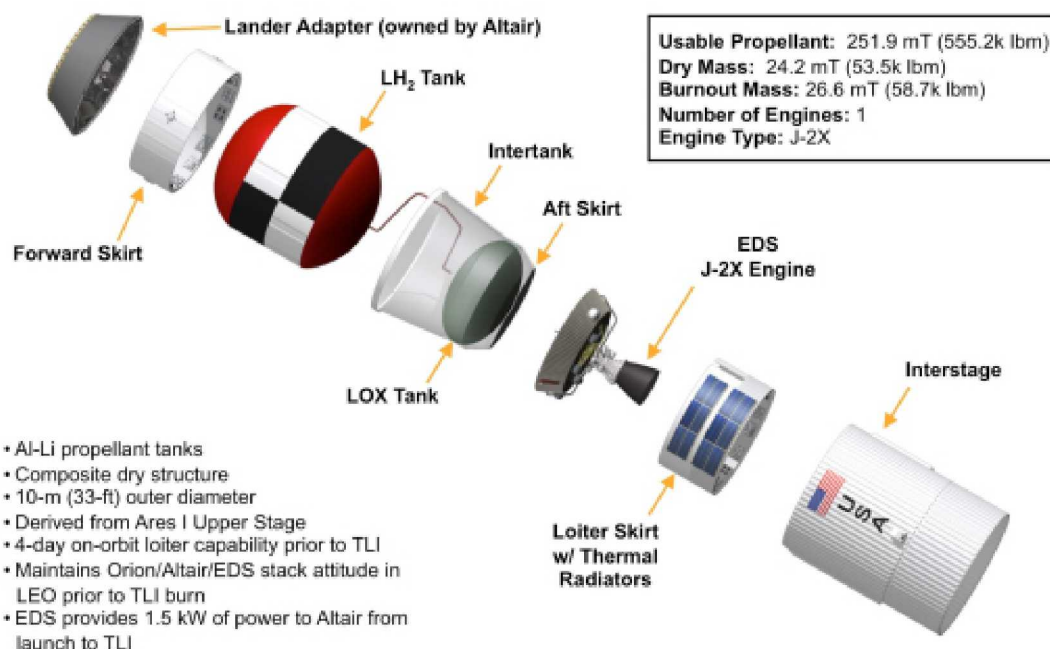


Fig. 11: Expanded view of 10-meter EDS structure including Interstage.



Fig. 12: First Friction Stir Weld of ET dome gore panels (left) and Al-Li panel structural buckling testing (right), both at MSFC.

Because Ares V requirements remain in a state of flux, engine development now is focused on the Ares I mission. Changes needed to support the Ares V loiter/vacuum start requirement, will have to be incorporated into the engine or the EDS via a kit-type modification. The current J-2X configuration is illustrated in Figure 13.

Because it is also used on the Ares I, it is in a relatively advanced stage of development, adhering closely to requirements and early risk reduction. A production engine contract is in place to produce five development ground test engines, two powerpack assemblies, four long lead hardware sets, one engine mass simulator nine nozzle extensions, and assorted spares such as fuel and oxidizer turbopumps, a hardware/software set for the engine hardware-in-the-loop simulation lab, engine support equipment, and component test articles.

The engine successfully completed its critical design review (CDR) in 2008. The design of the components is nearly complete, and several major components of the first development engines are in various stages of manufacturing and test as shown in Figure 14.



Fig. 13: The J-2X Upper Stage Engine for the Ares I and Ares V.

Supporting Heavy Lift Development

Much of the Ares V development team's effort in 2009 was devoted to supporting the work of the Review of U.S. Human Space Flight Plans Committee. A national heavy lift capability is a key part of the committee's 12-page summary report released in September 2009.³ Along with key questions regarding the future of the Space Shuttle, International Space Station, Earth to orbit transportation, and strategies for exploration, the committee pondered the question of what should serve as the basis for the next heavy-lift launch vehicle. Numerous studies since the Apollo program have endorsed a national heavy lift capability. The committee summary also endorsed heavy lift, saying: "A heavy-lift launch capability to low-Earth orbit, combined with the ability to inject heavy payloads away from the Earth, is beneficial to exploration, and it also will be useful to the national security space and scientific communities."

The committee's options were: the current Ares V, a more-directly Shuttle derived heavy lift vehicle or a launcher based on the current Evolved Expandable Launch Vehicle (EELV) family. The panel concluded that each approach has advantage and disadvantages. Considering the current Ares V-plus-Ares I system versus an architecture using two smaller versions of Ares V to launch Orion and the lunar lander, the committee preferred the later. That conclusion was based on options supplied by the Ares V team. Some of those options are illustrated in Figure 15.

The LCCR baseline (51.00.48) configuration is on the far left. Key features are five and a half segment boosters, extended core with six engines and earth departure stages. The 71 mT payload includes the Ares I.

At the far right is the direct launch capability to TLI of the PBAN booster options just to show the cargo launch capability of Ares V alone.

Four other options are shown in the middle of Figure 15. Along the top are crewed Ares V variants with an Ares I upper stage (left) and the reference EDS (right). The left-hand variant has a five-engine core, five-segment boosters, and a J-2X engine throttled to lower g loads. This was deemed to be the fastest heavy lift vehicle that NASA could build. This vehicle achieves 35 mT to TLI and would still have the upgrade path of a larger EDS for greater performance. All major components being developed for the Ares I – J-2X, five-segment PBAN booster, upper stage design – are used along with the development of a 33-foot core stage with NASA upgraded RS-68 engines. That core stage would then be the next building block for an even greater capability with the addition of a larger EDS, as shown in the right-hand concept. It increases performance

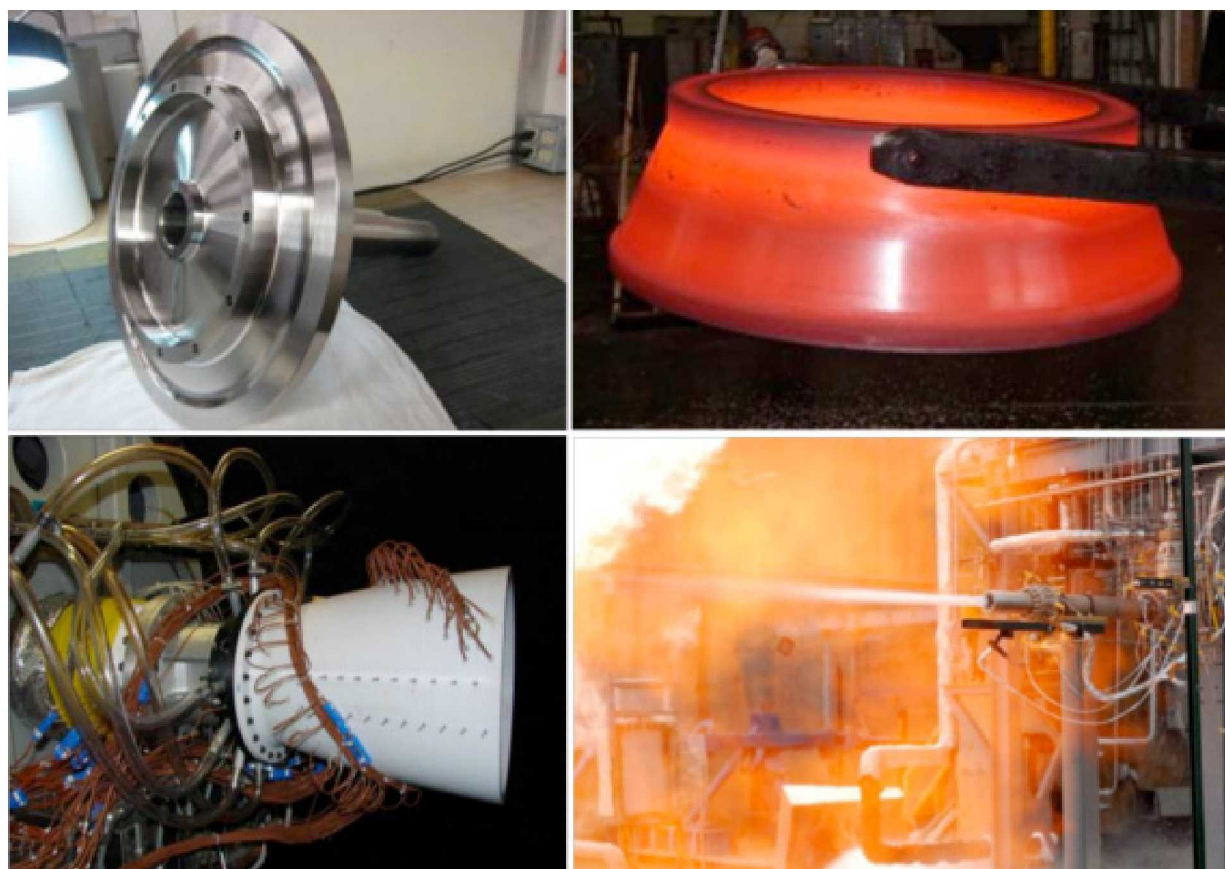


Fig. 14: Hardware and test progress on the J-2X includes clockwise from top left: OTP shaft and first stage blisk production nozzle turbine exhaust manifold base ring forging, workhorse gas generator/turbine simulator test, and supersonic film cooling effectiveness.

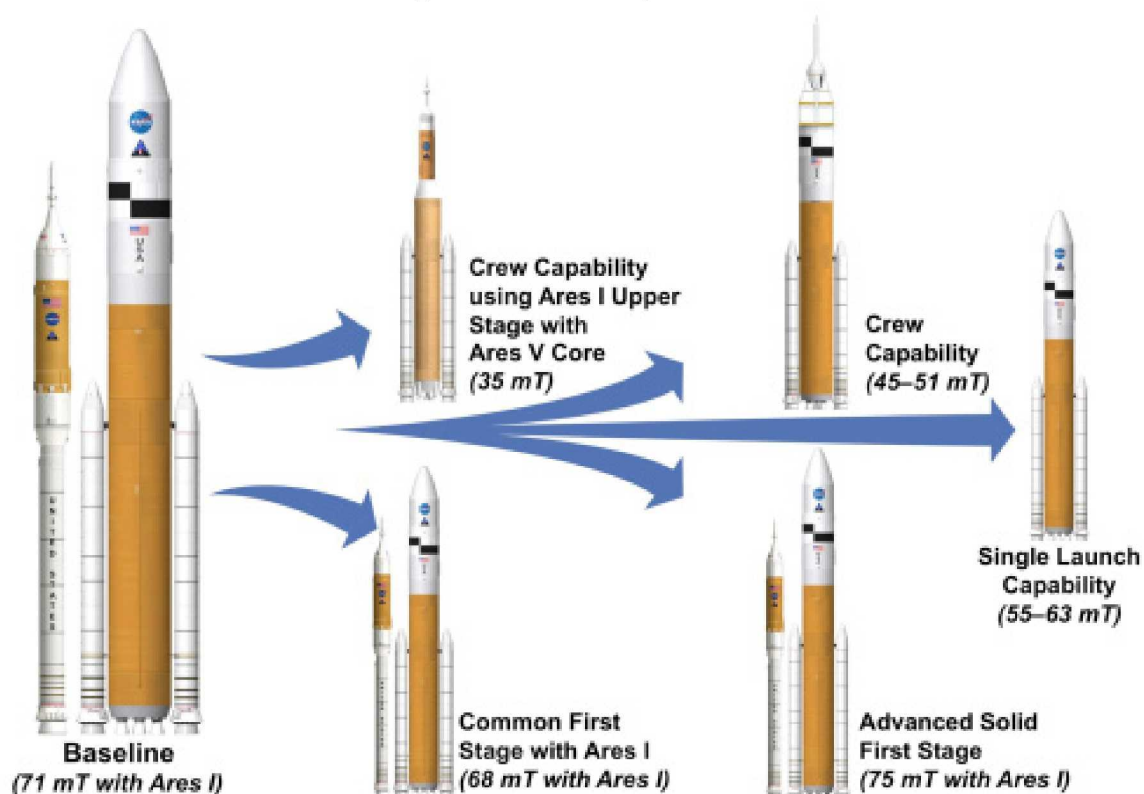


Fig. 15: Heavy lift options based the current Ares V reference vehicle, including key features and payload to TLI.

over the Ares I upper stage configuration by 10-16 mT. It may also be possible to upgrade the core stage along with the EDS development, so the 45-51 mT range reflects the upgrades to 5 ½ segment boosters and six RS-68 engines.

Along the bottom of Figure 15 are architectures that still include Ares I. If cost, schedule, etc. limit the booster development capability to that utilized on Ares I, then the performance loss is shown from the current 51.00.48 vehicle to the earlier 51.00.39 concept that served as entry point for the LCCR. However, if the booster development allows for an advanced booster, the 51.00.47 vehicle, including its more energetic HTPB propellant, composite case booster would result in the most powerful variant of Ares V shown in the figure. The 51.00.47 concept is still being carried as a trade study option in the current development phase. This variant also uses approximately the same core stage propellant load as the 51.00.48 vehicle by using an inert half segment in the booster to provide a direct comparison of the 5 ½ segment PBAN booster vs. the five-segment HTPB booster.

Conclusion

The Ares V design has matured significantly since the ESAS. In refining the design to meet the Constellation requirements, numerous configurations and mission concepts have been analyzed. It will be as technically and operationally safe, simple, and affordable as current technology can make it. NASA's focus for Ares V is the lunar mission. However, the Ares V represents a national asset. In that light, the Ares Projects are also reaching out to the academic and government community for payload and design inputs on science and military missions that may benefit from the Ares V capabilities. Every major space transportation study since Apollo has cited the need for a heavy lift capability. The Ares V concept definition phase has positioned NASA and the country to selected a heavy lift capability for the next stage of human exploration, scientific inquiry, and other endeavors of national importance.

References

1. NASA's Exploration Systems Architecture Study – Final Report, NASA TM-2005-214062, November 2005.
2. Creech, Steve; Sumrall, John P. Refining the Ares V Design to Carry Out NASA's Exploration Initiative. Paper No. IAC-08-D2.9.D16, Presented at the 59th International Astronautical Congress, Glasgow, Scotland, September/October 2008.
3. Review of U.S. Human Space Flight Plans Committee, Summary Report, Provided to the director, White House Office of Science and Technology Policy and NASA Administrator, September 8, 2009, Available at: <http://www.nasa.gov/offices/hsf/home/index.html>